Heavy-quark collectivity Light-quark thermalization at RHIC

Nu Xu

Physics goals at RHIC

Identify and study the properties of matter with partonic degrees of freedom.

Penetrating probes
- direct photons, leptons
- "jets" and **heavy flavor**

Bulk probes
- spectra, v_1, v_2 …
- partonic collectivity
- fluctuations

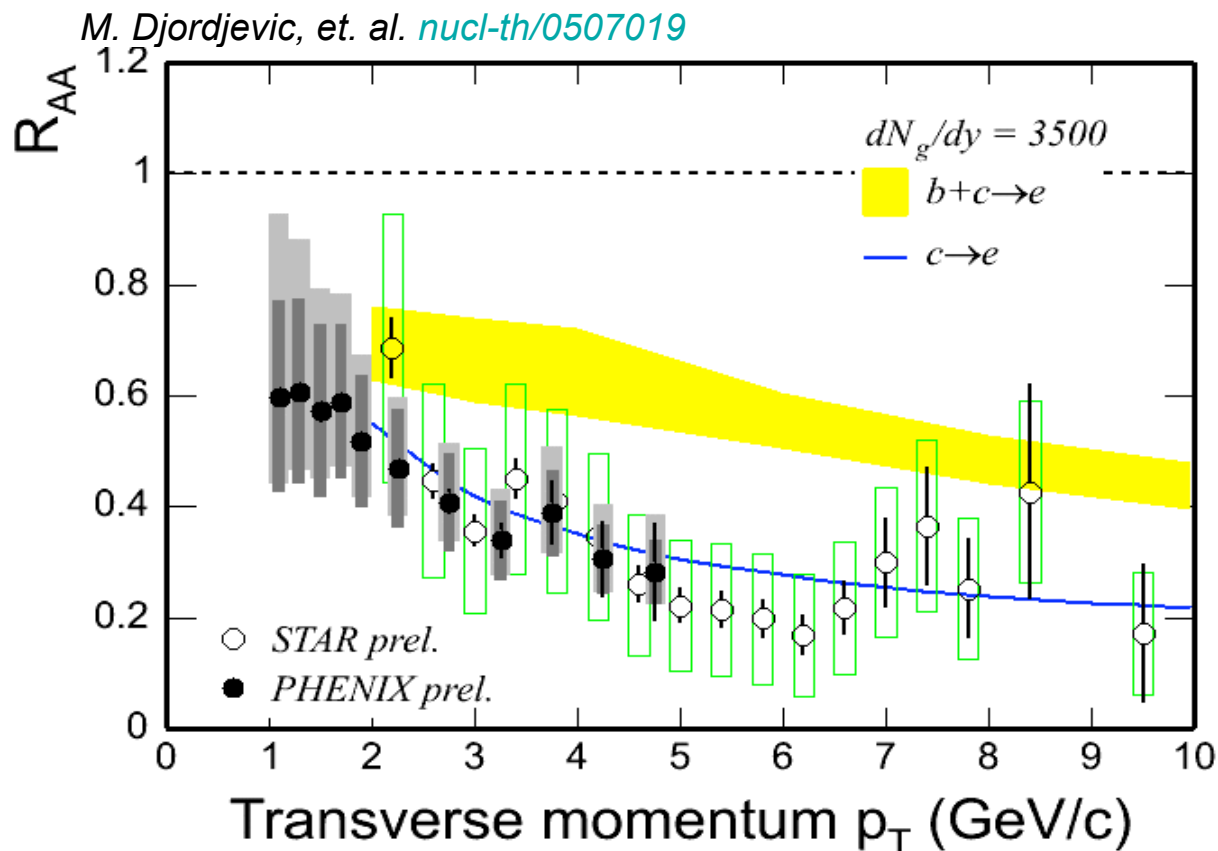| Hydrodynamic Flow	$=$	Collectivity	$\otimes$	Local Thermalization

What we have learned at RHIC

In Au + Au collisions:

(1) Partonic energy loss - tense interactions amongst partons

(2) Partonic collectivities and de-confinement

(3) Hadron yields in the state of equilibrium

Electrons: a mixture c- & b- hadrons

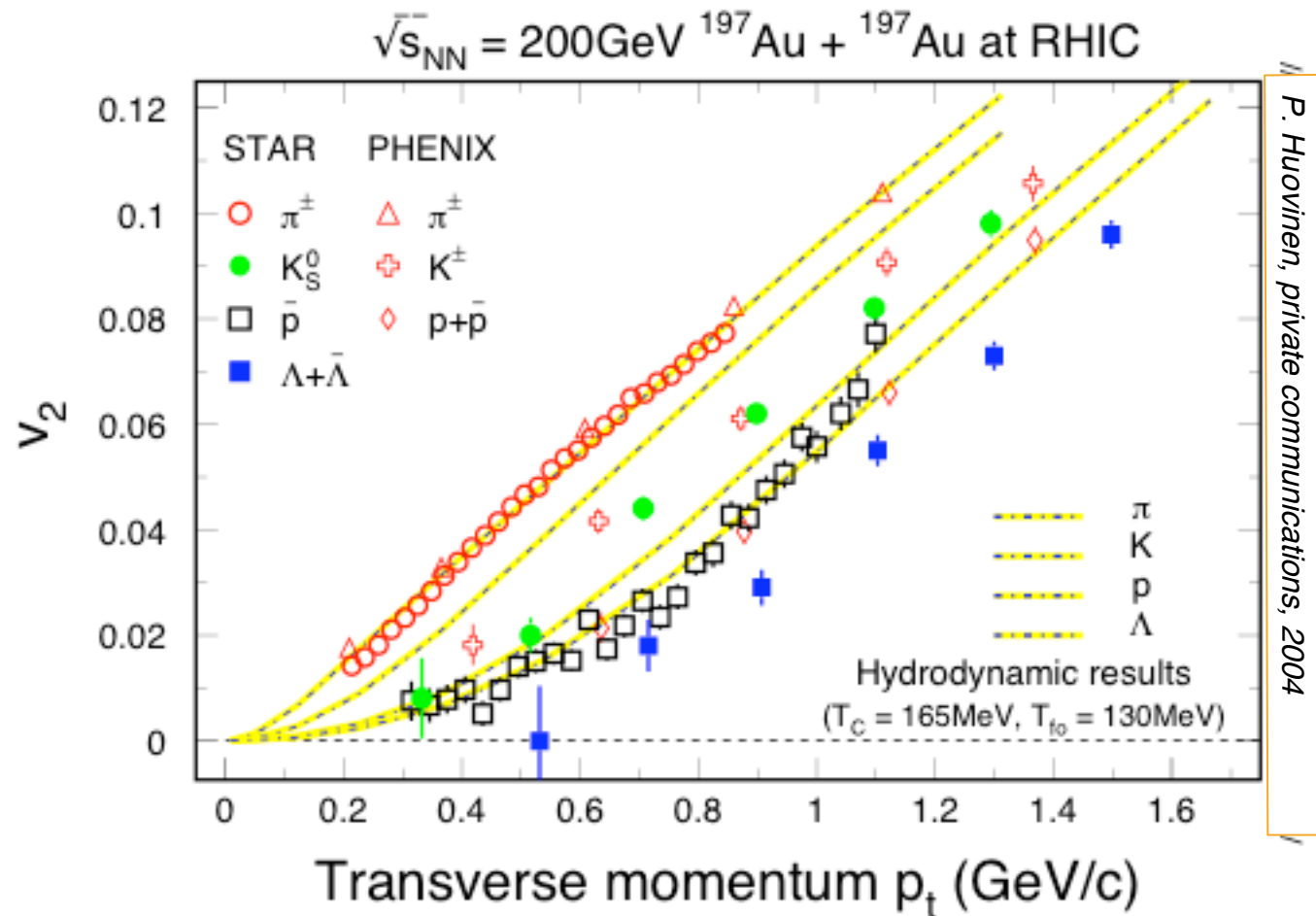M. Djordjevic, et. al. nucl-th/0507019

Partonic energy loss!
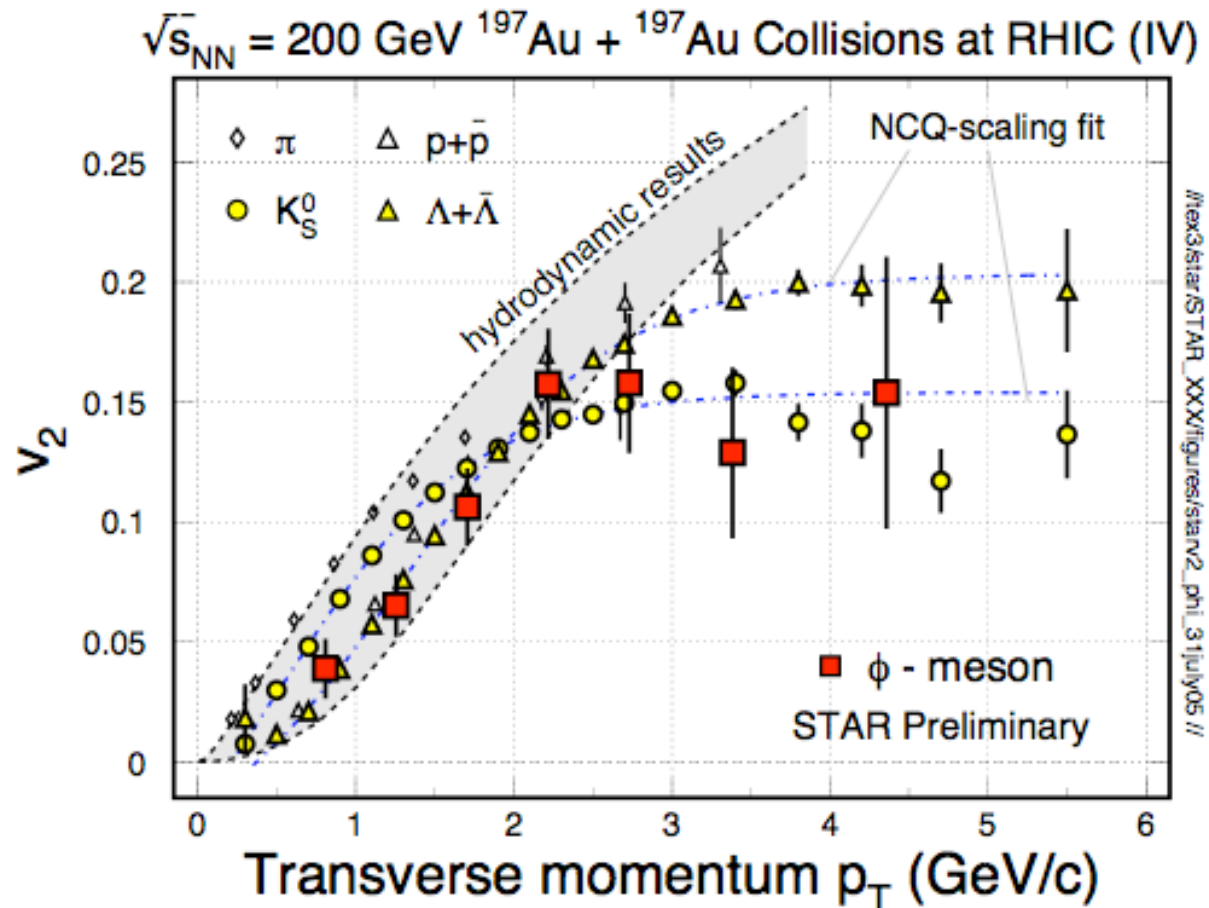Energy loss mechanism: under study   M. Gyulassy et al.
Problem: isolation Charm hadron contributions from Beauty-hadrons

v_2 at low p_T region

- Minimum bias data!   At low p_T, model result fits mass hierarchy well!
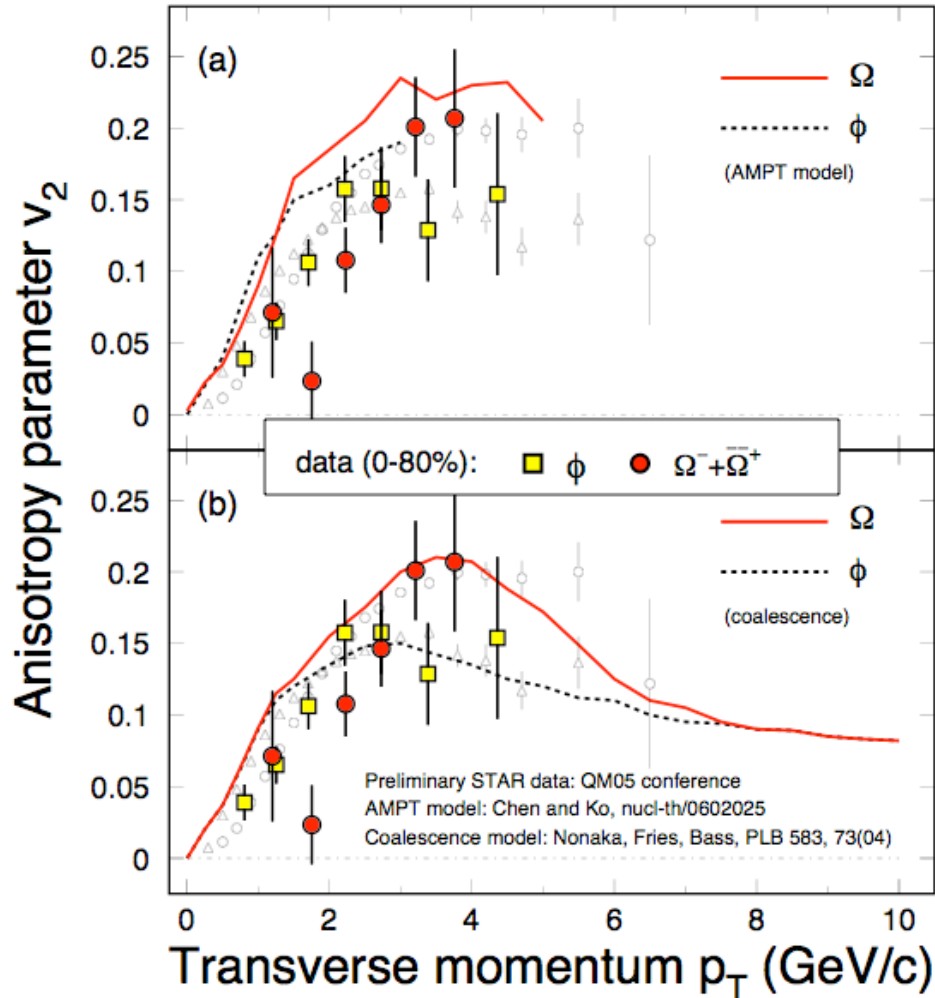- Details does not work, need more flow in the model!

φ-meson flows

STAR Preliminary, QM05 conference

S. Blyth et al.

Dynamic model results

Models seem to work in $2.5 < p_T < 5$ GeV/c

In those models, almost no interactions at the late hadronic stage. Flow developed prior to hadronization:
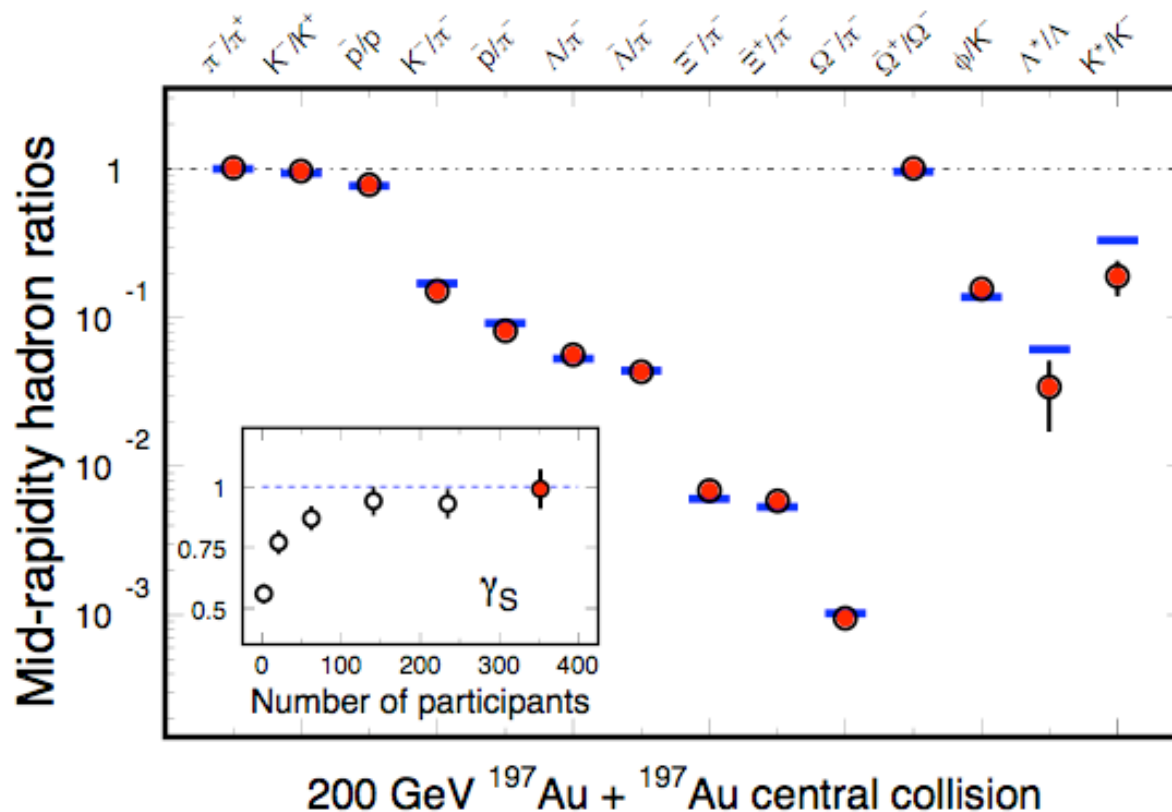
⇒ **partonic collectivity**

⇒ **de-confinement**

See talks by:
 Bellweid, Blyth, Fachini, Gyulassy, Heinz, Hwa, Lu, Oldenburg, Sorensen, Zhang, Zhong

Figure labels:
- (a) AMPT model
- (b) coalescence
- Ω, φ

data (0-80%): □ φ ● $\Omega^- + \overline{\Omega}^+$

Preliminary STAR data: QM05 conference
AMPT model: Chen and Ko, nucl-th/0602025
Coalescence model: Nonaka, Fries, Bass, PLB 583, 73(04)

Anisotropy parameter v_2

Transverse momentum p_T (GeV/c)

Yields ratio results

200 GeV ^{197}Au + ^{197}Au central collision

- In central collisions, thermal model fit well with γ_S = 1. **The system is thermalized at RHIC.**
- Short-lived resonances show deviations. **There is life after chemical freeze-out.**

RHIC white papers - 2005, Nucl. Phys. *A757*, STAR: p102; PHENIX: p184.

What we have learned at RHIC

In Au + Au collisions:

(1) Partonic energy loss - tense interactions amongst
     partons
(2) Partonic collectivities and de-confinement
(3) Hadron yields in the state of equilibrium

In order to demonstrate the possible early partonic thermalization, we need the heavy flavor collectivity measurement. This is an experimental issue.

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Bulk probes
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- partonic collectivity
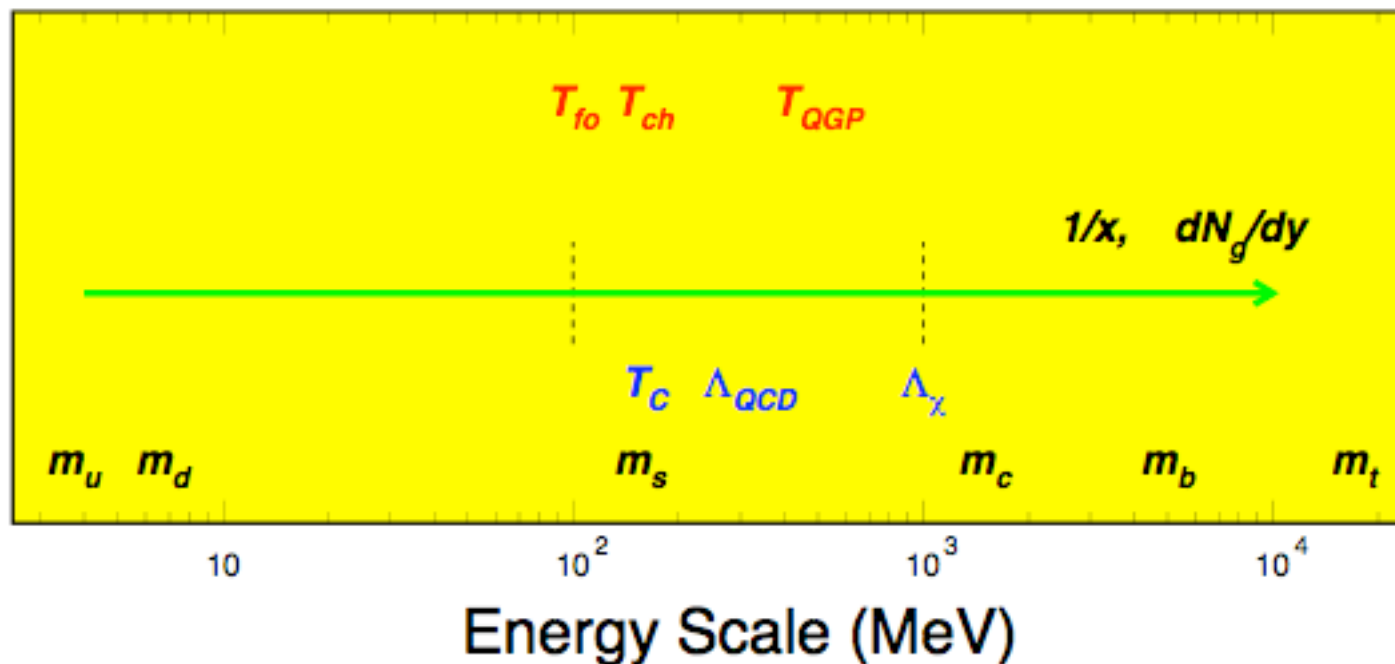- fluctuations

Hydrodynamic Flow	=	Collectivity	$\otimes$	Local Thermalization

QCD Energy Scale

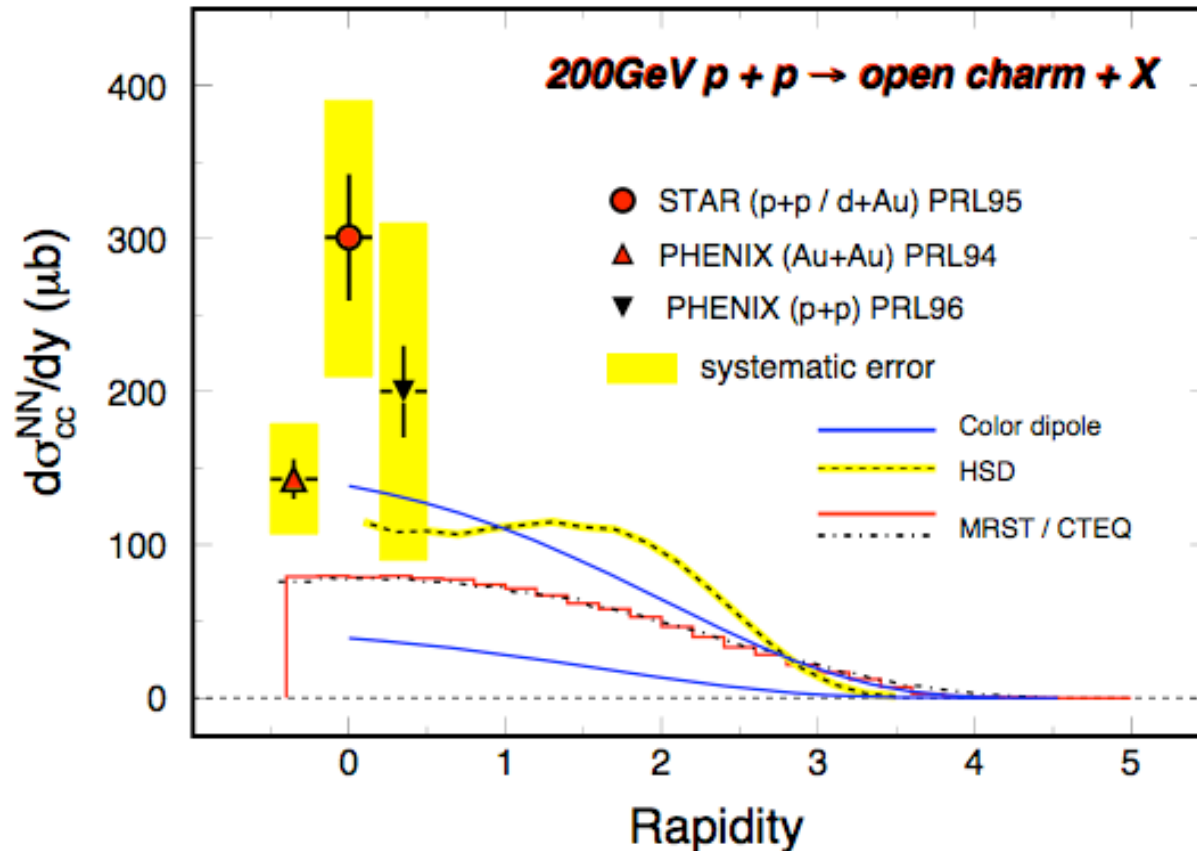| m$_s$ ~ 0.2 GeV, similar to values	m$_c$ ~ 1.2 - 1.5 GeV >> Λ_{QCD}
T$_C$ critical temperature Λ_{QCD} QCD scale parameter T$_{CH}$ chemical freeze-out temperature $\Lambda_\chi = 4\pi f_\pi$ scale for χ symmetry breaking	- pQCD production - parton density at small-x - QCD interaction - medium properties R$_{cc}$ ~ 1/m$_C$ => color screening J/ψ => deconfinement and thermalization
u-, d-, s-quarks: *light-flavors*	c-, b-quarks: *heavy-flavors*

quark mass
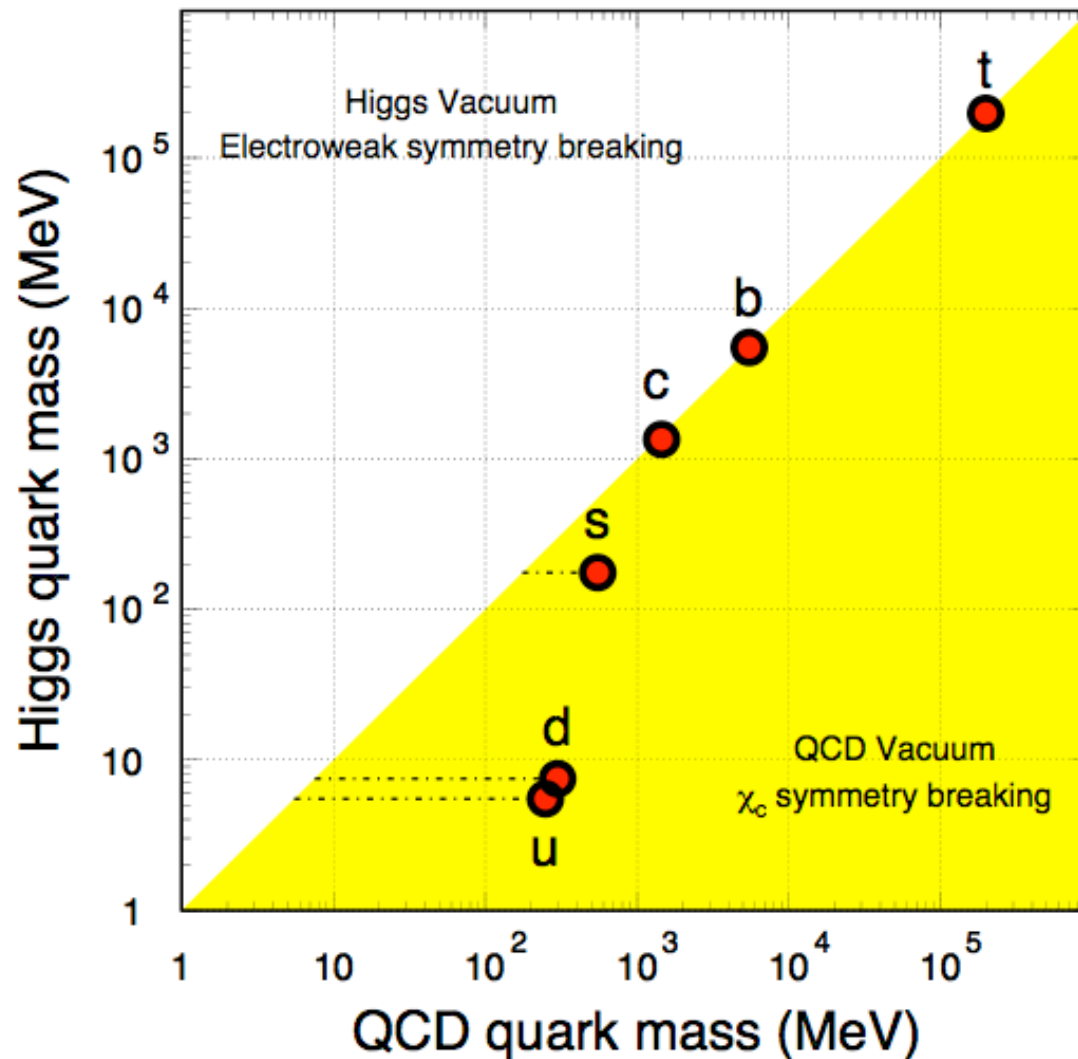
1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

⇨ Strong interactions do not affect heavy-quark masses.

Charm cross sections

200GeV p + p → open charm + X

- ● STAR (p+p / d+Au) PRL95
- ▲ PHENIX (Au+Au) PRL94
- ▼ PHENIX (p+p) PRL96
- ▢ systematic error

- —— Color dipole
- – – – HSD
- ·—·—· MRST / CTEQ

y-axis: $d\sigma_{c\bar{c}}^{NN}/dy$ (μb)

x-axis: Rapidity

First set of measurements, systematic errors are large. Precision data are needed:
 - energy loss analysis ⇒ test pQCD in hot and dense medium
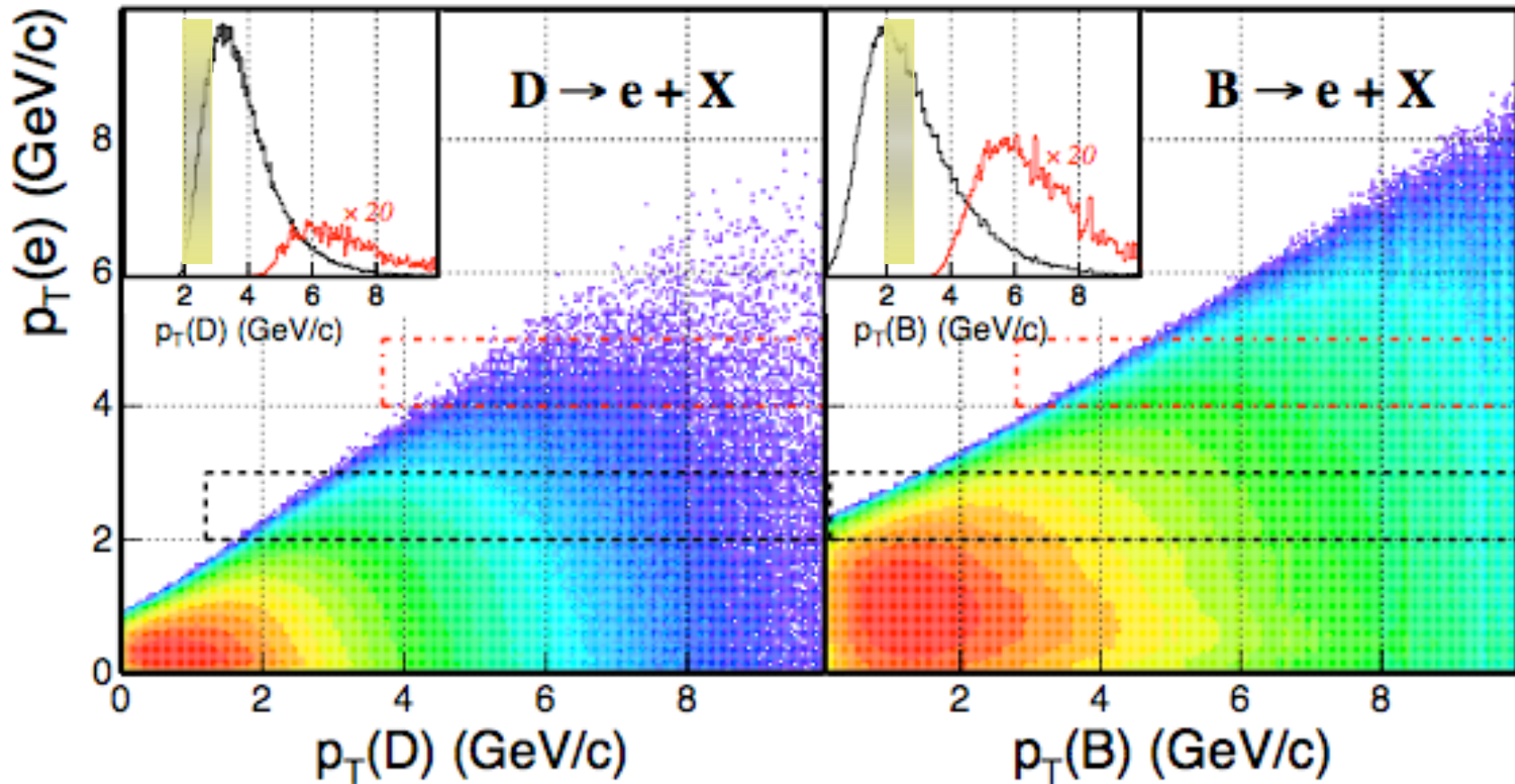 - J/ψ analysis ⇒ test Charm thermalization and de-confinement

Non-photonic electron v_2
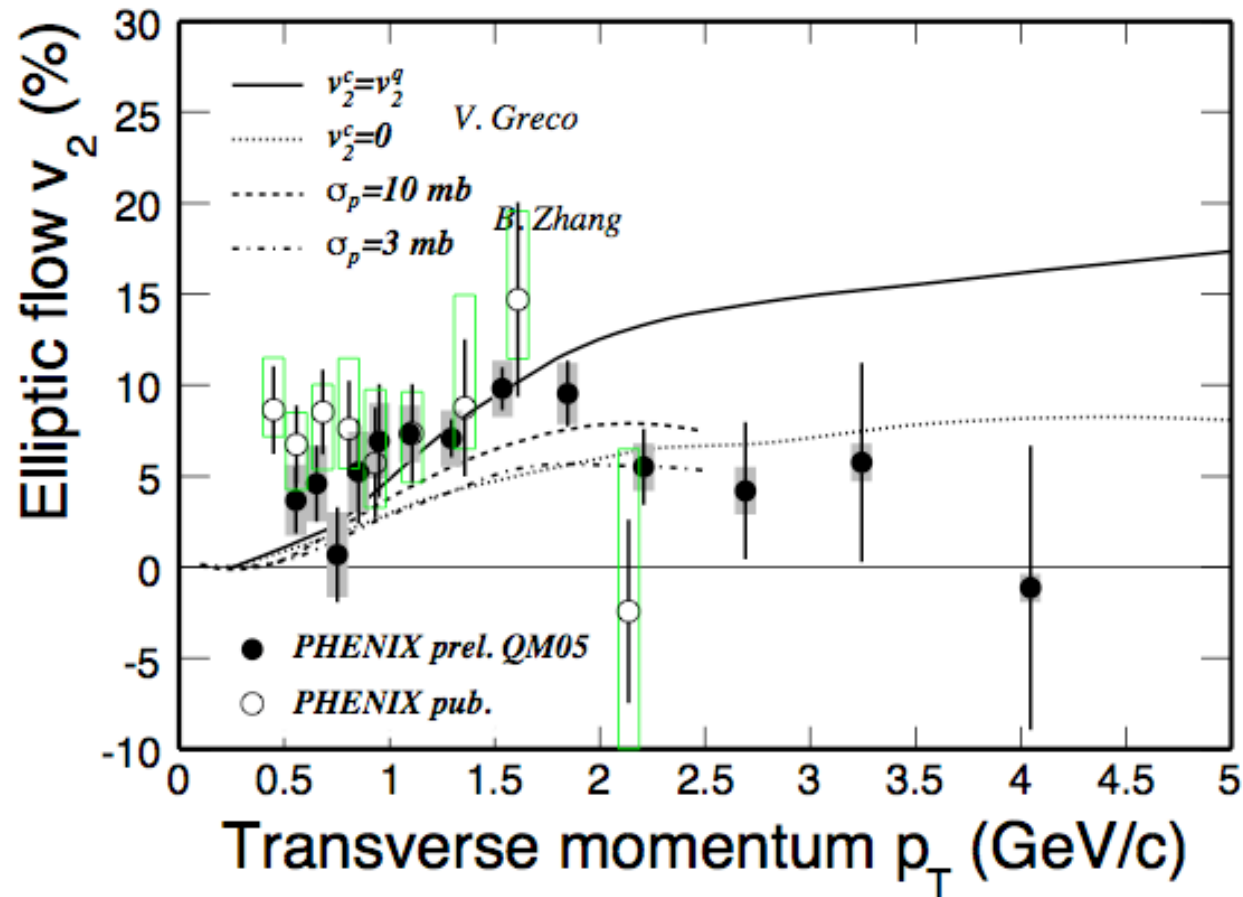
Charm flows - a hint for partonic thermalization at RHIC!

Problem: Decay effect?

Decayed electron p_T versus D- and B-hadron p_T

The correlation between the decayed electrons and heavy-flavor hadrons is weak.

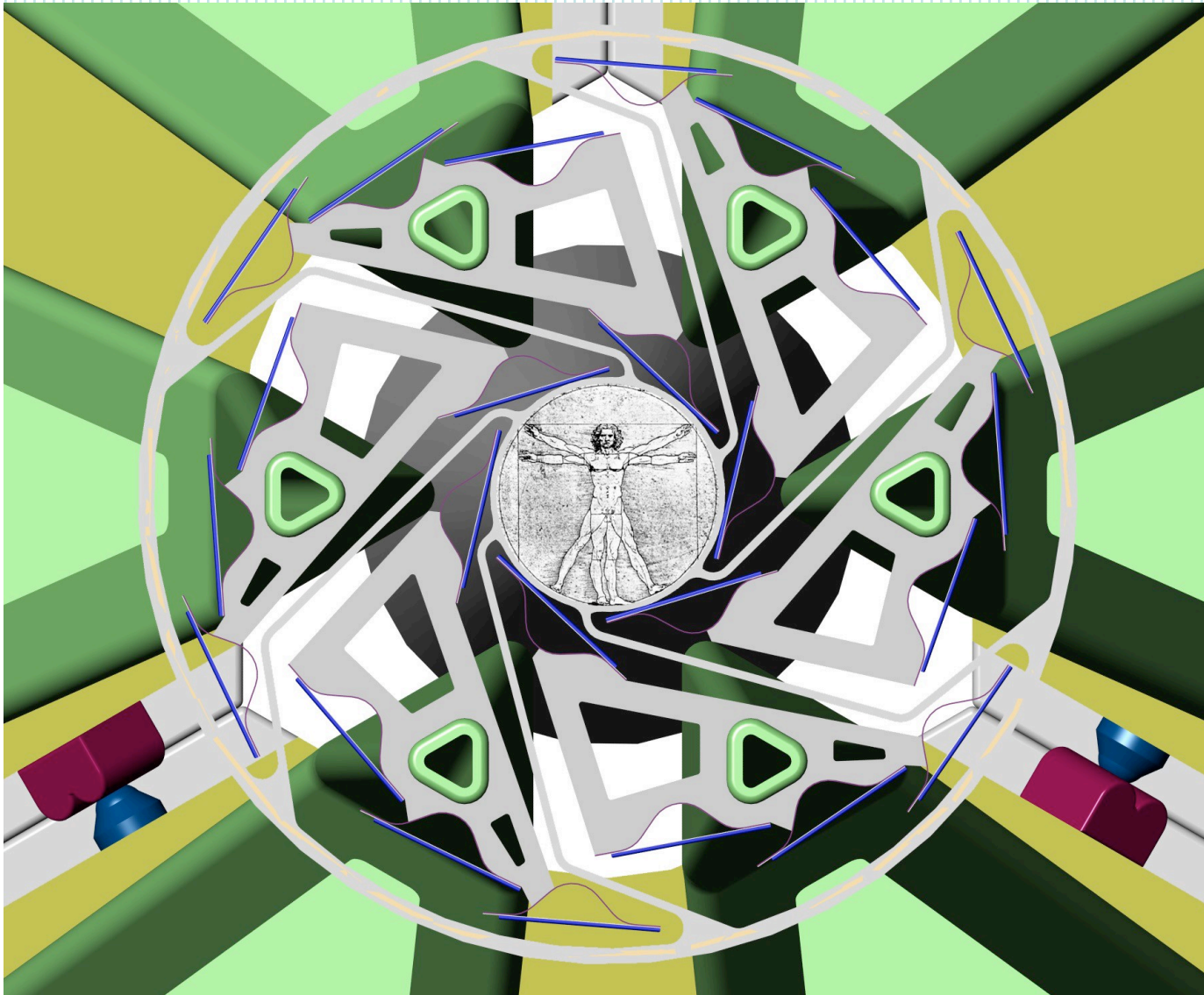Pythia calculation   Xin Dong, USTC October 2005
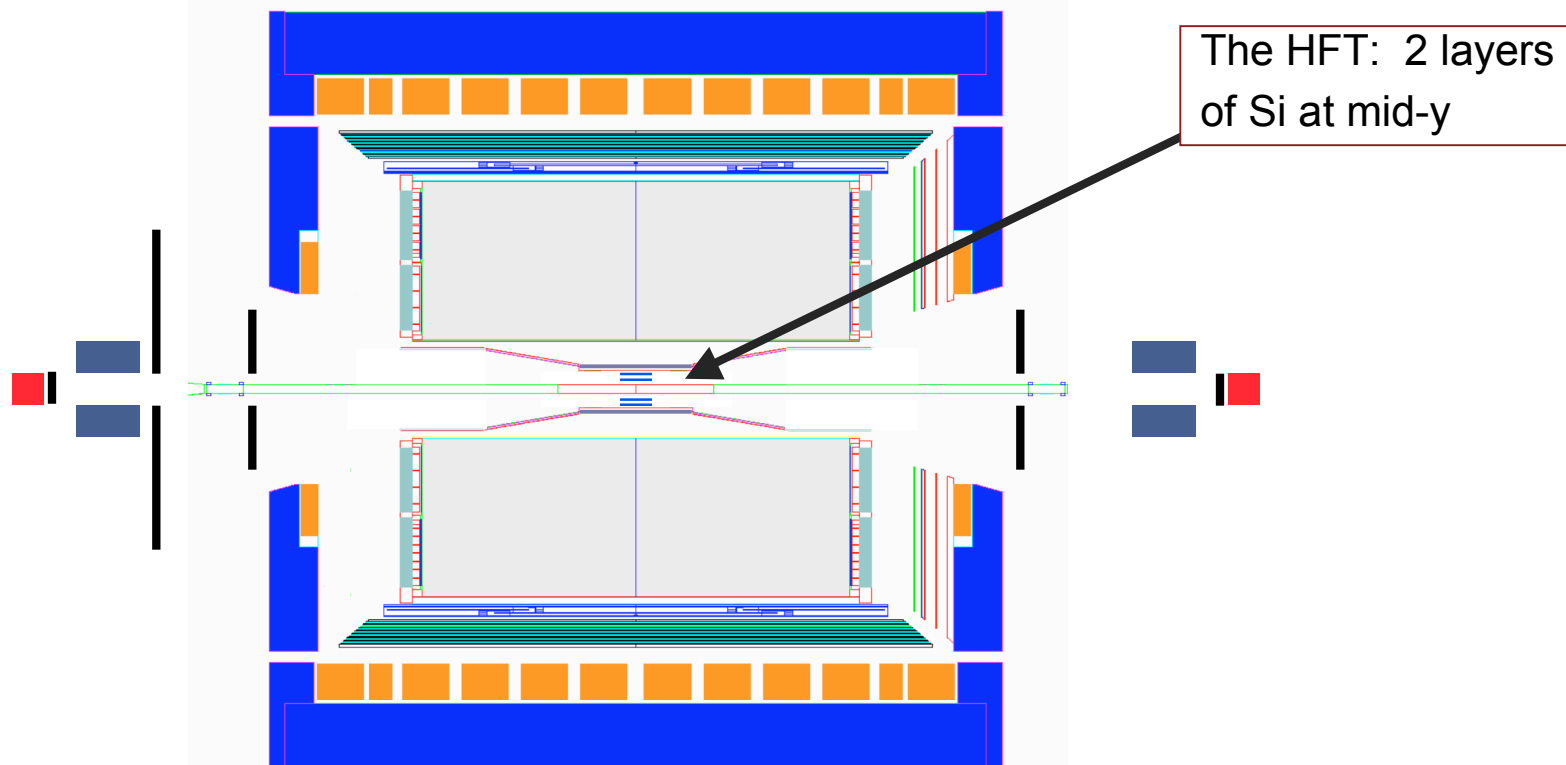
Challenges to electron spectra

1) Decay kinematics and the correlations

2) Separate Charm-hadron from Beauty-hadrons

3) Possible collective 'flow' at the low p_T region

4) Chemistry of heavy flavors

# Direct Topological Identification of Charm-Hadrons in STAR

# The Heavy Flavor Tracker


The HFT: 2 layers of Si at mid-y

1) A new detector: 30 μm silicon pixels to get excellent resolution at the vertex

2) Direct topological reconstruction of Charm hadrons

3) Analyze charm hadron Flow and Energy loss

The HFT Mechanical Design

- Two Layers of Si
  - 1.5 cm radius
  - 5 cm radius
- High Resolution
  - 100M pixels
  - 30 x 30 μm^2
- Thin – with low MCS
  - 50 μm thinned Si
  - 0.36% radiation length
  - 0.5 mm beam pipe
  - CMOS technology
- 24 Ladders
  - 10 chips, 2 x 20 cm^2
  - 100 mW/cm^2 power budget
  - air cooled

side-view

end-view
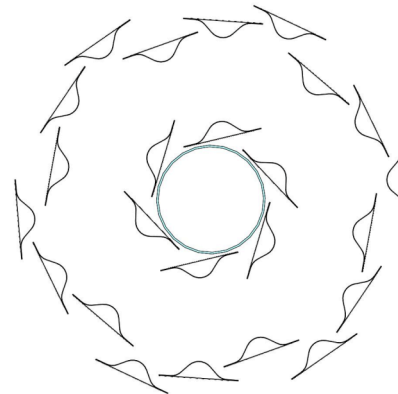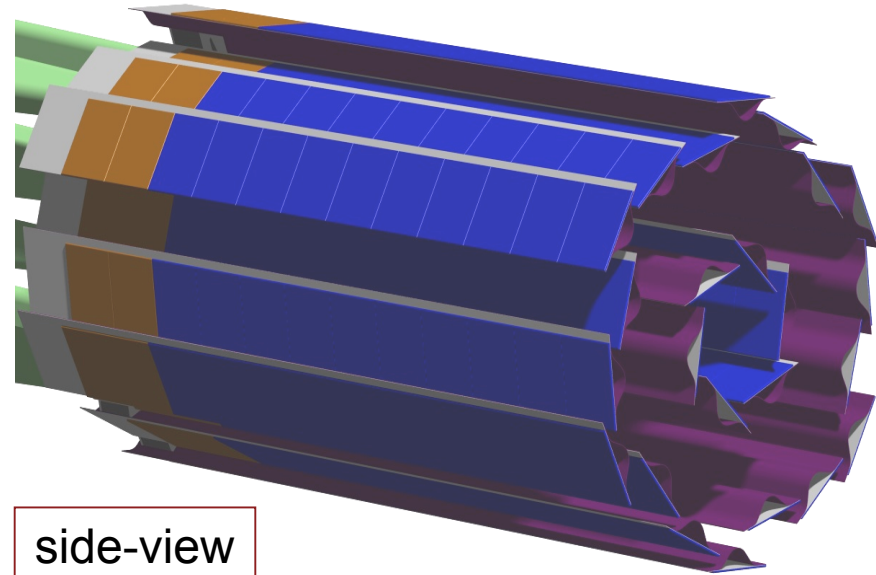
Open-charm hadron reconstructions
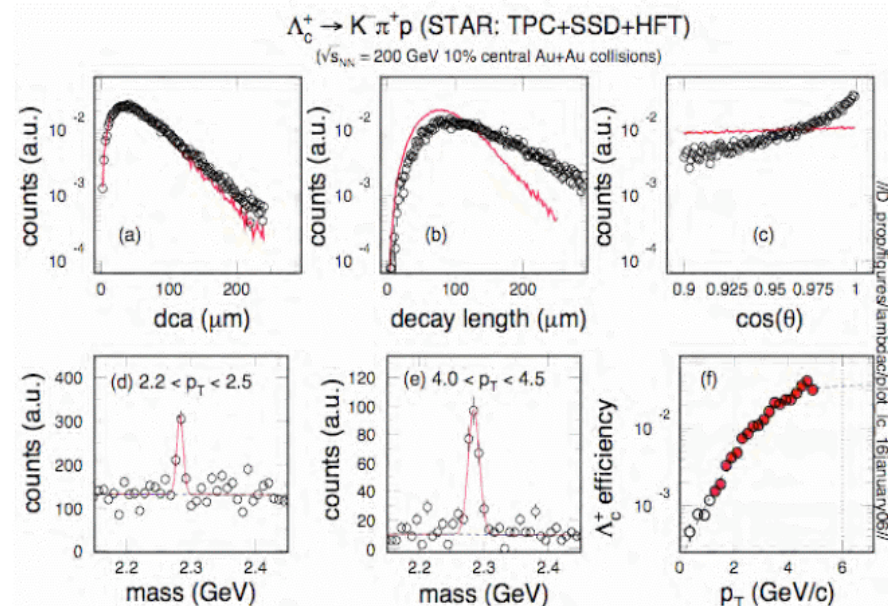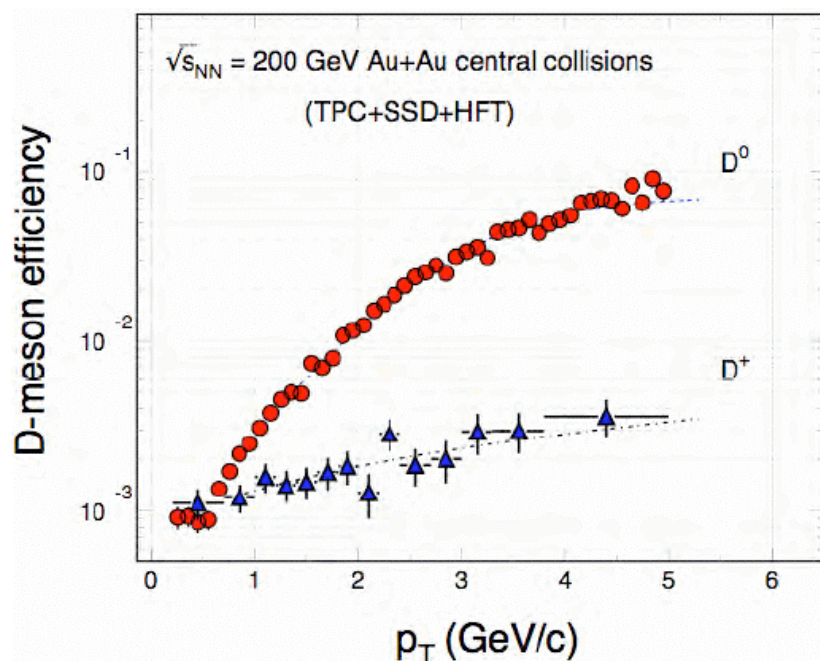
1) **D^0, D_s, D^+, Λ_c** and their anti-particles can be reconstructed with the combination of the HFT+SSD*+TOF+TPC.
2) Decent reconstruction efficiencies at low p_T region - important for flow analysis.

      * Place holder for any adequate intermediate tracking device, such as IST.

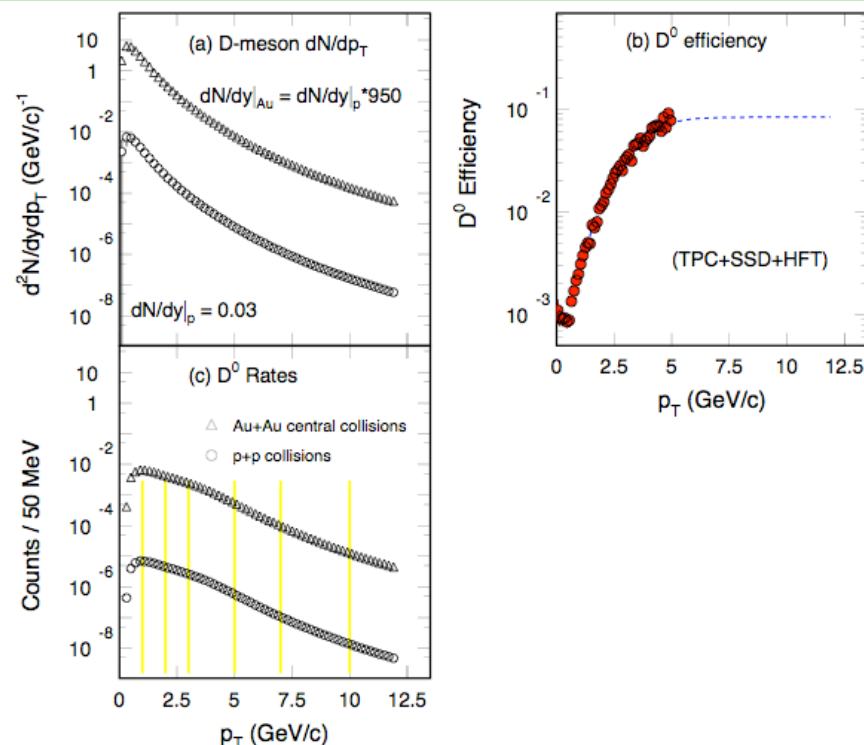# Rates estimate - spectra

(a) **dN/dp$_T$ distributions for D-mesons.**

The integrated yield dN/dy = 0.03 as measured in p + p collisions at 200 GeV

----Phys. Rev. Lett. 94, 062301 (2005)

Scaled by <N$_{bin}$> = 950, corresponds to the top 10% central Au + Au collisions at RHIC.

(b) **3-σ significance D^0 efficiency with TPC+SSD+HFT.**

(c) **D^0 rates from p+p and top 10% central Au + Au collisions at 200 GeV.**

p$_T$ (GeV/c)	Δp$_T$ (GeV/c)	# of Events (p + p)	# of Events 0-10% Au + Au (N$_{bin}$ = 950)	# of Events 0-80% Au + Au (N$_{bin}$ = 290)
1.0	0.5	44×10^6	0.45×10^6	1.75×10^6
2.0	0.5	70×10^6	0.45×10^6	1.75×10^6
3.5	1.0	70×10^6	0.45×10^6	1.75×10^6
5.5	1.0	350×10^6	0.75×10^6	3×10^6
7.5	1.0	1200×10^6	3.5×10^6	11×10^6
10.5	1.5	7500×10^6	9×10^6	30×10^6

Rates estimate - v_2

(a) dN/dp_T distributions for D-mesons.

Scaled by $<N_{bin}> = 290$, corresponds to the minimum bias Au + Au collisions at RHIC.
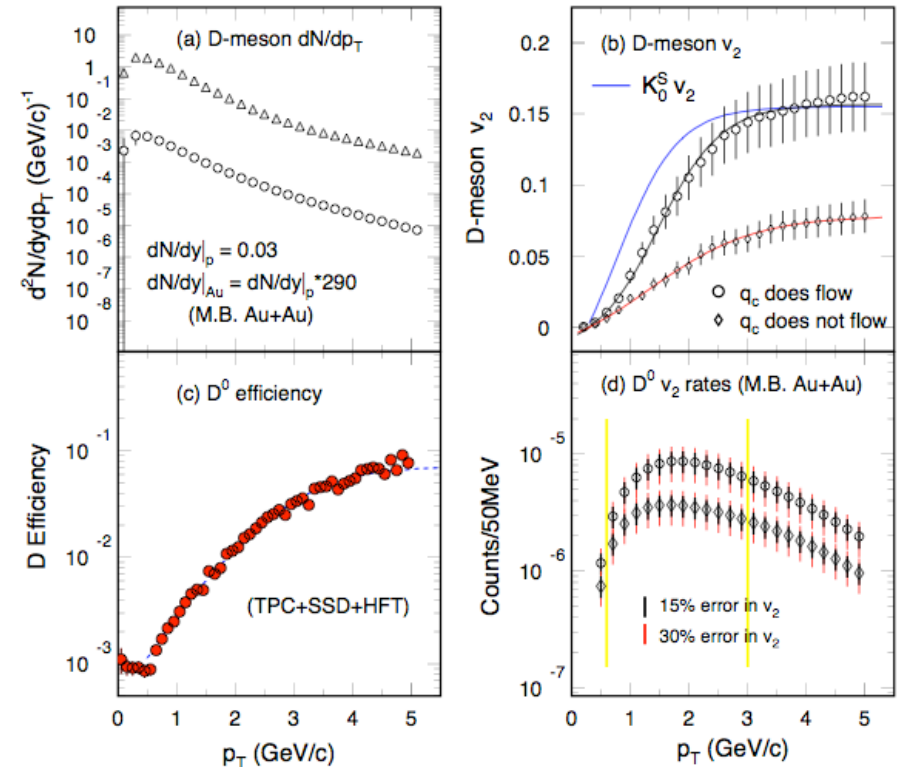
(b) Assumed v_2 distributions for D-mesons.

---- PLB 595, 202 (2004)

Error bars shown are from 15% systematic errors

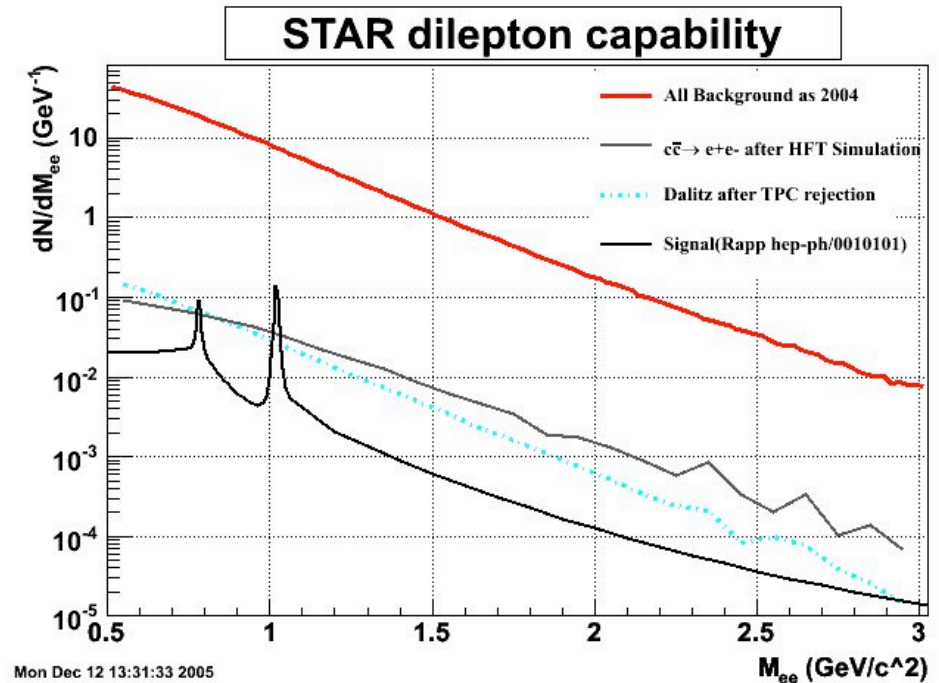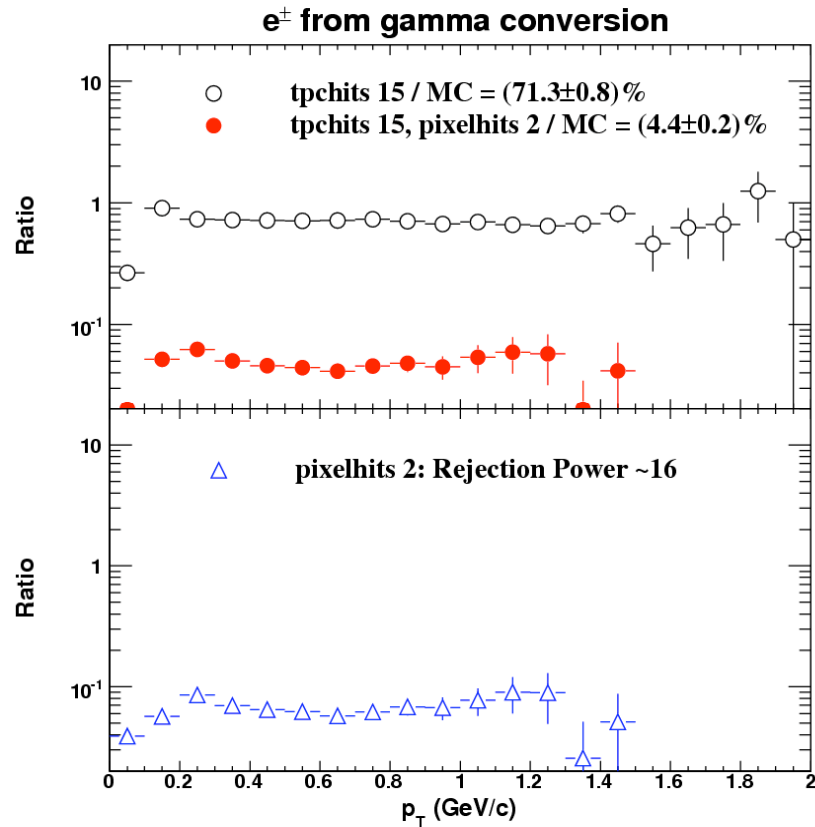**(c) 3-σ significance D^0 efficiency with TPC+SSD+HFT.**

(d) D^0 meson v_2 rates from minimum bias Au + Au collisions at 200 GeV.

The small and large error bars are for 15% and 30% systematic errors, respectively. For the v_2 analysis, 12 bins in φ are used.

p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events q_c does not flow
0.6	0.2	260×10^6	525×10^6
1.0	0.5	70×10^6	140×10^6
2.0	0.5	53×10^6	125×10^6
3.0	1.0	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

Vector meson reconstructions

e± from gamma conversion

tpchits 15 / MC = (71.3±0.8)%
tpchits 15, pixelhits 2 / MC = (4.4±0.2)%

pixelhits 2: Rejection Power ~16

STAR dilepton capability

- All Background as 2004
- $c\bar{c} \rightarrow e+e-$ after HFT Simulation
- Dalitz after TPC rejection
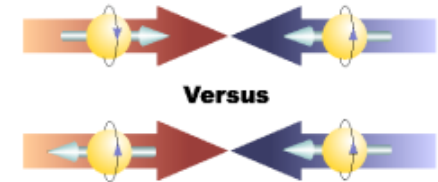- Signal(Rapp hep-ph/0010101)

Mon Dec 12 13:31:33 2005

1) Enhanced background rejection power for vector meson reconstructions via di-leptons - a factor of 15-20
2) Important to test Chiral symmetry restoration physics

Heavy flavor in Spin physics

Inclusive electrons from charm

$A_{LL}(e)$

~100pb⁻¹, ~70% pol.

GRSV standard
GRSV minimum
GRSV maximum

p_T (GeV/c)
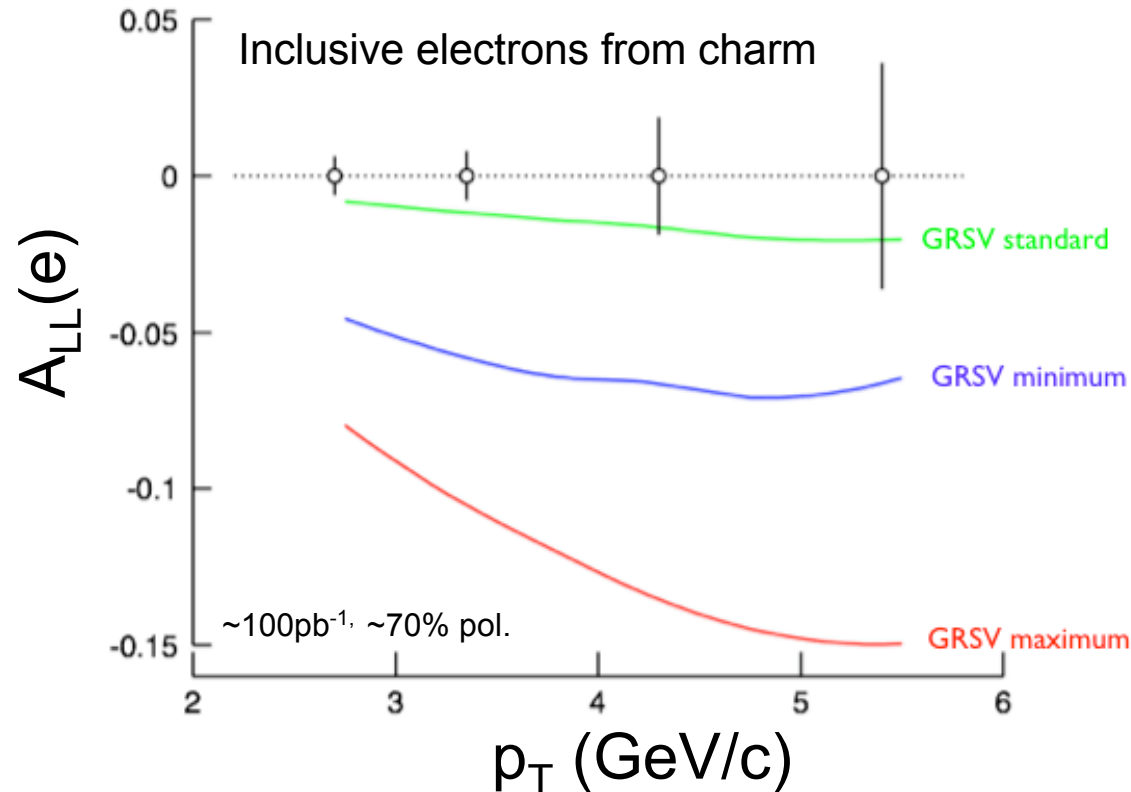
Heavy flavor production is gluon dominated, Spin sorting,

Versus

gives direct access to gluon polarization.

1) Heavy flavor mass sets a natural scale; need to separate charm and beauty
   -- displaced vertices measurement ⇒ *HFT*.
2) HFT alone has a limited spin program at top RHIC luminosity ⇒ *IST*.

from *E. Sichtermann's talk*

Summary

STAR upgrades = future of RHIC!

(1) Test pQCD properties in hot and dense medium

- Charm- and bottom-hadron spectra, R_{AA}, charm correlations
- Sensitive and detailed study for partonic energy loss $\Rightarrow$
    `falsify pQCD,   *a la Miklos'*
- Precision Charm cross section for J/ψ analysis - direct test
    de-confinement and Charm thermalization

(2) Test light-flavor thermalization

- Charm-hadron v_2 - partonic thermalization
- Di-lepton invariant mass distributions - χ_c symmetry

Summary

STAR upgrades = future of RHIC!

IST: Intermediate Si-Tracker

- Important for p+p and peripheral ion collisions

- Essential for spin physics

- Tremendous enhancement for heavy ion program

Others talks and links

At this meeting:

    Yifei Zhang - Charm-hadron reconstructions

    Yan Lu - Background

    Howard Wieman - R&D

    Steve Steadman - Review

    Andrew Rose - HFT Software

    G. van Nieuwenhuizen - IST/FST

    E. Sichtermann - heavy flavor in Spin physics

Other links:

- http://www.star.bnl.gov/protected/future/
- http://www-rnc.lbl.gov/~nxu/group/starhft.html